TO INVESTIGATE LEACHATE TREATMENT POTENTIAL OF FUNGUS CRUDE ENZYMES IMMOBILIZED WITH METALLIC NANOPARTICLES

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TABLE OF CONTENT

	Page No.
Abstract	3
Chapter 1 Introduction	4
Chapter 2 Review of literature	5
Chapter 3 Collection and physicochemical characterization of leachate samples from solid waste dumping site	6
Chapter 4 Synthesis and physicochemical characterization of nanoparticles	9
Chapter 5 Extraction and Characterization of crude enzyme from the fungus and preparation of metallic Nanoparticle based enzyme conjugates	12
Chapter 6 Treatment of leachates with Nanoparticle based enzyme conjugates and optimization of different parameters	15
Chapter 7 Conclusion and Future Aspects	21
Publications	22
Conferences	24

Abstract

This research investigates the potential of using crude enzymes from the fungus *Phanerochaete chrysosporium*, immobilized with metallic nanoparticles, for the treatment of landfill leachate. The study focuses on the synthesis and characterization of titanium dioxide (TiO_2) nanoparticles and their conjugation with fungal enzymes to enhance the degradation of leachate contaminants. Leachate samples were collected from the Pirana Solid Waste Management site in Ahmedabad, Gujarat, and underwent comprehensive physicochemical characterization. The TiO_2 nanoparticles were synthesized using a sol-gel method and characterized by various techniques, including SEM, FTIR, and XRD, to confirm their morphology and structural properties. Enzymes extracted from *P. chrysosporium* were characterized and immobilized onto the nanoparticles, forming nanoparticle-enzyme conjugates. The effectiveness of these conjugates in treating leachate was evaluated through various parameters such as pH, total dissolved solids (TDS), electrical conductivity (EC), chemical oxygen demand (COD), and ammonia nitrogen (NH_3–N) levels. The results demonstrated a significant reduction in these parameters, indicating the successful degradation of organic and inorganic pollutants. The study also compared the efficacy of different conjugation polymers, including calcium alginate and chitosan, in enhancing the stability and activity of the enzyme-nanoparticle conjugates. Immobilized enzyme-nanoparticle (NpChBs) conjugates offer a promising approach for the bioremediation of landfill leachate, providing an efficient and sustainable solution for mitigating environmental pollution. Future research should focus on optimizing the synthesis process and exploring the scalability of this method for industrial applications.

Chapter 1: Introduction

India generates an estimated 62 million tons of municipal solid waste annually, with significant discrepancies in data collection and management across urban and state levels. Only 20% of the daily 1.50 lakh metric tons (MT) of solid waste is processed, while the remaining 80% is dumped in landfills, leading to the generation of highly toxic leachate. This leachate contains high concentrations of organics, ammonia nitrogen, heavy metals, and hazardous chemicals, posing severe environmental and health risks. The waste management sector in India is evolving with initiatives aimed at sustainable development and compliance with waste management rules by the Ministry of Environment and Forest (MoEF). However, challenges such as inconsistent enforcement of regulations, lack of public awareness, and participation in waste segregation and recycling persist.

Leachate treatment methods include biological, chemical, and physical processes. Traditional methods are often insufficient to manage the complex composition of leachate, necessitating advanced treatment approaches. Nanomaterials, particularly titanium dioxide (TiO_2) nanoparticles, show promise in enhancing leachate treatment through adsorption, catalysis, and microbial conjugation. The integration of nanotechnology with bioremediation offers a potent solution for pollutant degradation. However, the application of nanomaterials requires careful consideration of their potential environmental and health impacts.

The combination of nanoparticles with enzymes and microorganisms represents an innovative strategy for effective leachate treatment. This research aims to explore the synthesis, characterization, and application of TiO_2 nanoparticle-based enzyme conjugates to improve the degradation of leachate contaminants, contributing to sustainable waste management practices in India.

Objectives of Present Work

1. Collection and physicochemical characterization of leachate samples from solid waste dumping site
2. Synthesis and physicochemical characterization of nanoparticles
3. Extraction and Characterization of crude enzyme from the fungus and preparation of metallic Nanoparticle based enzyme conjugates

4. Treatment of leachates with Nanoparticle based enzyme conjugates and optimization of different parameters

Chapter 2: Review of literature

2.1 Different role of nanomaterial in leachate and waste water treatment

In particular, the application of nanomaterial in water and wastewater treatment has drawn wide attention properties like surface area, fast kinetics, fast dissolution, high dispersion ability, adjustable pore size and surface chemistry, superparamagnetic for particle separation, specific affinity towards certain contaminant. Different role of Nanomaterial and its uses for wastewater treatment are below

- Photocatalyst
- Adsorbent
- Nanomaterial based bioremediation techniques

Type of Nanomaterials	Combined Organisms or Biological systems	Pollutants	Out comes
TiO_2		Leachate	46% COD removal efficiency
$Cu@FeO_3$		Leachate	Removal of COD, TOC, TP, NO_2-N, NO_3-N respectively 79.4%, 62.6%, 85%, 98.1%, 84.2%
WO_3		Leachate	54.91 With WO_3. Value increased to 77.45% after UV radiation.
ZnO		Leachate	Toxicity reduced by more than 79%.
MNPs + Ca alginate	*P. crysosporium*	Leachate	Maximum adsorbent capacity
Fe_3O_4	*E. taxodii*	Leachate	Maximum removal of sulfonide

Nitrogen-doped TiO_2	*P. crysosporium*	Leachate	Removal of TOC and NH_3–N are75% and 74%
Nanomembranes		Industrial wastewater	20% pollutants removal
Nanotubes	enzyme organophosphate hydrolase	Water	22% pollutants removal
	P. ostreatus and laccase	Micropollutant	bisphenol-A degradation achieved
	P. ostreatus and laccase	TrOCs	
	B. adusta and cellulose as co substrate	Leachate	Removal of COD 63%

Chapter 3: Collection and physicochemical characterization of leachate samples from solid waste dumping site

Leachate Sample Collection

The Pirana MSW site in Ahmedabad, Gujarat, is crucial for waste management studies due to its significant environmental impact. Operational for decades, this site has led to the generation of leachate, a liquid byproduct that poses severe risks to groundwater and surface water. To assess this impact, a comprehensive leachate sampling operation was conducted, collecting ten samples (see Table 1) from various locations within the landfill. These samples were preserved in plastic bottles to maintain their chemical integrity and labeled for traceability. The sampling locations and the systematic approach are illustrated in Figure 1 and Figure 2.

Table 1: Geographical details of collected leachate samples

Sample Number	Latitude	Longitude	Sample ID	Location Name
1	22.982171	72.564916	LO1	Excel Industries Entrance
2	22.981278	72.566978	LO2	SWM Hill side road
3	22.982274	72.56755	LO3	Old hill side

4	22.982421	72.567846	LO4	Old hill side
5	22.979421	72.563616	LO5	Road side
6	22.981762	72.56466	LO6	Old hill side
7	22.981758	72.56551	LO7	5-6 FEET
8	22.981758	72.56552	LO8	9-10 FEET
9	22.981742	72.56546	LO9	14-15 FEET
10	22.979848	72.563691	LO10	ROAD SIDE 1

Figure 1: Collected 10 leachate samples

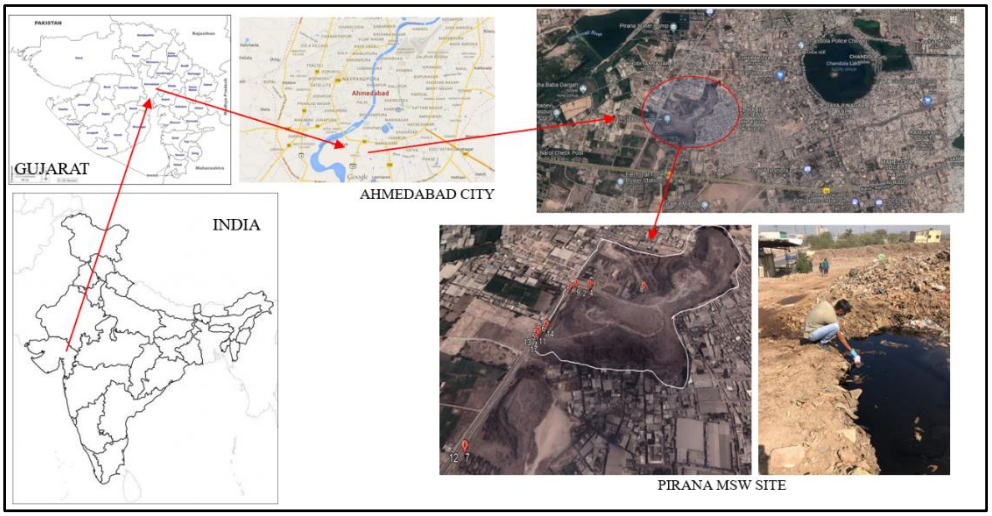


Figure 2: Sample location map SWM, Pirana, Ahmedabad

Physicochemical Characterization

Key parameters measured included:

- **pH**: Indicates acidity or alkalinity.

- **Total Dissolved Solids (TDS)**: Reflects the combined content of all inorganic and organic substances.
- **Electrical Conductivity (EC)**: Measures the leachate's ability to conduct electricity.
- **Chemical Oxygen Demand (COD)**: Quantifies the amount of oxygen required to oxidize organic and inorganic matter.

These measurements are essential for assessing the leachate's pollution level and understanding its potential environmental impacts. The results are summarized in **Table 2** and **Table 3.4**.

Table 2: Physicochemical parameters for leachates

Leachate Characterization	Method/Instrument	Steps
Determination of pH, TDS, EC	Hand held Meter, Hanna (HI98129)	• Sample collection
Determination of NH_3-N (Ammoniacal N)	Distillation-titration method	• Sample preparation • Analysis
Determination of COD	Open reflux method	• Acid Digestion and titration
Heavy metal	ICPMS	

Table 3: Results of characterization of leachate Sample

Parameters	Min – Max	Average	Standard Deviation
pH	7.9 – 8.5	8.288	±0.11811
TDS (ppm)	17,060 – 24,720	19,880	±1,899.71
EC (mS)	18.72 – 25.48	23.387	±12.0728
COD (mg/L)	5,000 – 20,520	9,238.10	±2,376.18
NH_3–N (mg/L)	1,200 – 2,450	2,064	±1,131.18

Heavy Metal Analysis

The analysis of heavy metals in leachate samples was conducted using Inductively Coupled Plasma Mass Spectrometry (ICPMS). The results from Table 3.5 revealed varying concentrations of metals such as arsenic (As), cadmium (Cd), mercury (Hg), lead (Pb),

chromium (Cr), and nickel (Ni). Notably, arsenic and cadmium were below detection limits, while mercury and lead were detected in measurable amounts.

Table 4: Heavy metal analysis of raw leachates

Metals Detected	Metal Leachates (mg L-1)
As (ppm)	BDL
Cd (ppm)	BDL
Hg (ppb)	0.23
Pb (ppm)	0.16
Cr (ppm)	0.70
Ni (ppm)	0.47

Further analysis showed chromium (Cr) and nickel (Ni) at concentrations of 0.70 ppm and 0.47 ppm, respectively. The presence of chromium and nickel at these levels could be attributed to the degradation of metal alloys and industrial wastes, which are commonly disposed of in landfills. Chromium, in particular, is known for its dual oxidative states, which can affect its mobility and toxicity in the leachate environment. The levels observed suggest moderate leaching from the waste, necessitating ongoing monitoring to ensure they remain within safe limits as per environmental regulations. The presence of these metals in leachate underscores the importance of stringent waste management practices and the need for robust landfill design to minimize the release of hazardous substances into the environment.

Chapter 4: Synthesis and physicochemical characterization of nanoparticles

Synthesis of TiO_2 Nanoparticles

TiO_2 nanoparticles were synthesized using the sol-gel method adapted from Hu et al., 2016. The process involved preparing two solutions:

- **Solution A**: A mixture of ultrapure water, glacial acetic acid, and absolute ethyl alcohol in a 2:3:10 ratio with added carbamide.

- **Solution B**: Absolute ethyl alcohol mixed with titanium butoxide in a 4:1 ratio.

Solution B was gradually added to Solution A while stirring to ensure uniform particle distribution. The mixture was aged overnight and dried at 80°C for four hours to form a gel, which was then ground into a fine powder and calcined at 500°C for three hours to enhance its

structural properties and photocatalytic

Figure 1: a) Dried gels, crystal structure (80 ◦C, 3 h); b) Grinded gels for fine powder of nanoparticles

Characterization of TiO2 Nanoparticles

Dynamic Light Scattering (DLS) Analysis

DLS was used to measure the size distribution of the synthesized TiO_2 nanoparticles, showing an average particle size of approximately 80 nm, indicating a uniform size distribution.

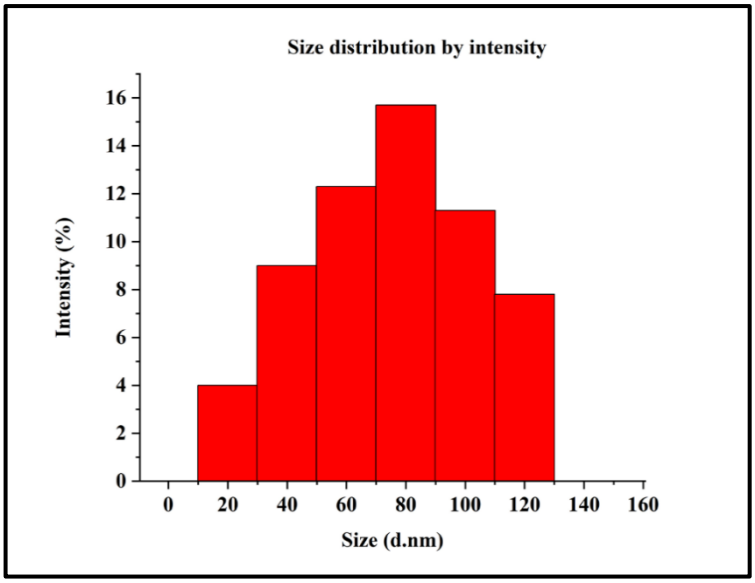


Figure 2: Particle diameter as ascertained from DLS experiment for TiO_2 nanoparticles (≈80 nm)

Scanning Electron Microscope (SEM)

SEM image of TiO_2 nanoparticles synthesized using the sol-gel method, Figure 5. The image showcases the aggregated structure and rough surface texture of the nanoparticles, as specified by the annotations.

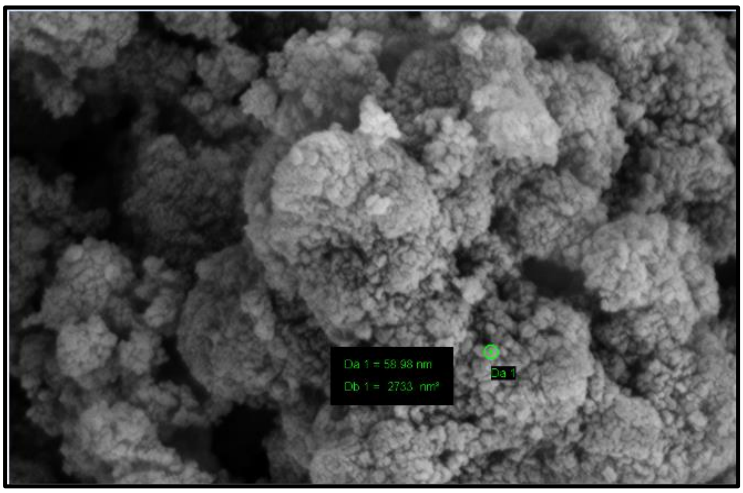


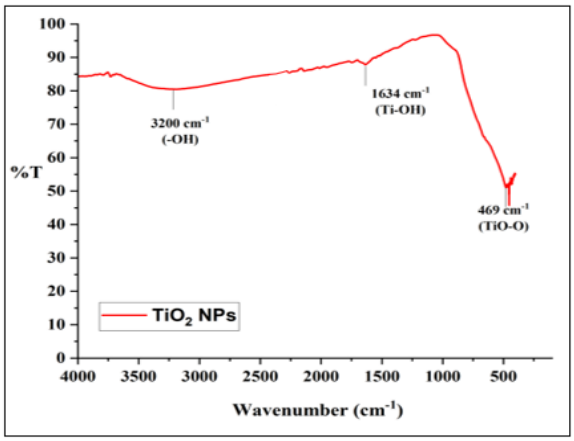
Figure 3: SEM images of TiO_2 nanoparticle

Fourier-Transform Infrared (FT-IR) Spectroscopy

The FTIR spectrum showed distinct absorption bands:

- 469 cm^{-1}: Ti-O bending mode.
- 1634 cm^{-1}: Deformative vibration of Ti-OH groups.
- Around 3200 cm^{-1}: Stretching vibrations of hydroxyl groups.

- These bands confirmed the presence of Ti-O bonds and surface hydroxyl groups, crucial for applications like photocatalysis.



Functional group	IR Values Absorptions (cm^{-1})
OH	3200
Ti-OH	1634
TiO-O	469

Figure 4: FTIR spectra for TiO_2 nanoparticles

X-ray Diffraction (XRD)

The XRD pattern was used to determine the crystallographic structure of the TiO_2 nanoparticles. Peaks at 25.3°, 37.8°, and 48.0° indicated the predominance of the anatase phase.

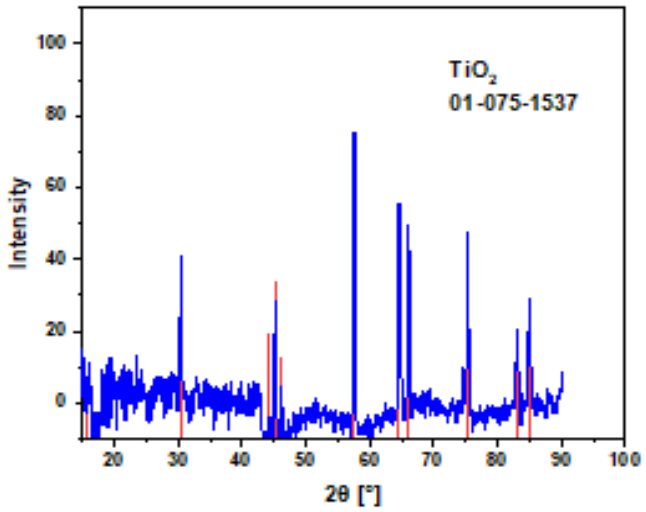


Figure 5: XRD pattern of Synthesized TiO_2

Chapter 5: Extraction and Characterization of crude enzyme from the fungus and preparation of metallic Nanoparticle based enzyme conjugates

Selection of White Rot Fungi and Synthesis

The white-rot fungal strain *P. chrysosporium* BKMF-1767 was sourced from the National Chemical Laboratory (NCL) in Pune, India. The fungal spores were subcultured on potato dextrose broth (PDB) media, followed by incubation at 25°C for 48 hours. This cultivation was essential for preparing the strain for subsequent experiments, including enzyme synthesis and immobilization for treatment processes.

Characterization of *P. chrysosporium* and Enzyme Extraction

Bromophenol Cotton Blue Staining

Fungal identification was performed using lactophenol cotton blue staining, highlighting the colonies and morphological characteristics of *P. chrysosporium* (seeFigure. 8).

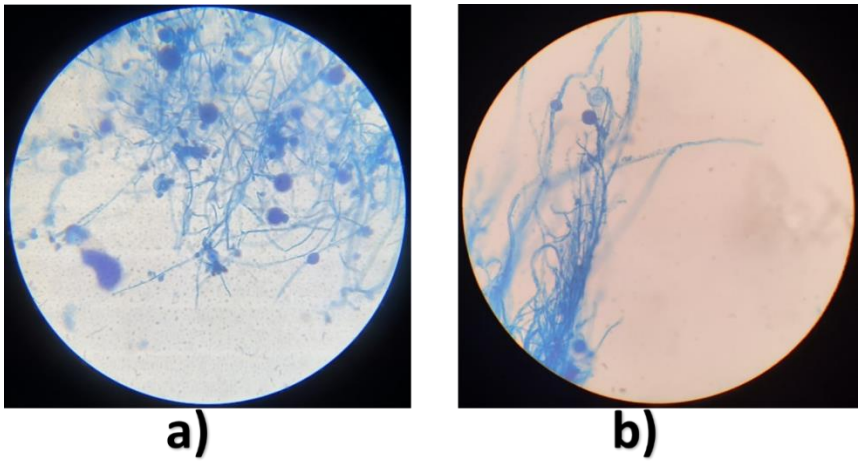


Figure 8: (a), (b) Microscopic images of fungi after staining with lactophenol cotton blue. *P. chrysosporium*

Extraction of Crude Enzyme

Crude enzyme extraction followed the method by Sana et al., 2019. The fungal culture was centrifuged, and the supernatant was filtered and collected for further analysis.

Total Protein Estimation by Lowry's Method

The protein concentration in the extracted crude enzyme was determined using the Lowry method, yielding 1349 µg/ml.

Confirmation Tests for Crude Enzyme

Enzymatic activity was confirmed using lignin peroxidase (LiP) and manganese peroxidase (MnP) substrate plates, where clear zones around wells indicated enzyme activity.

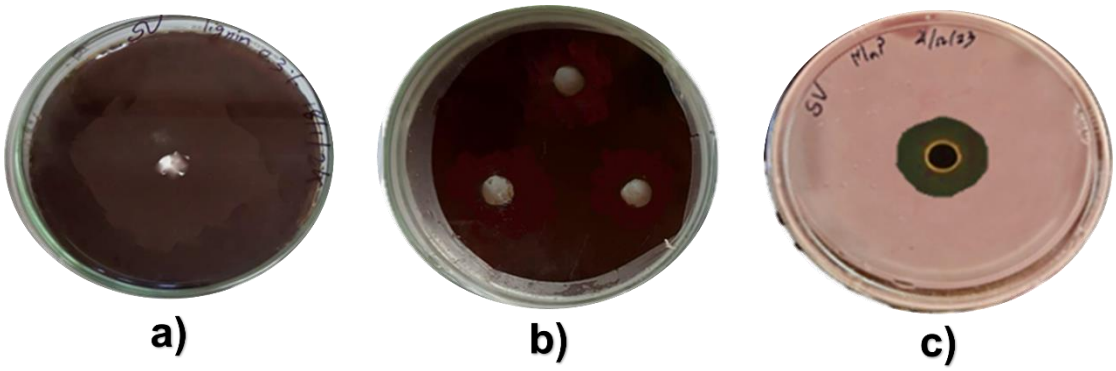


Figure 9: Enzyme activity: Zone of clearance (a) Lignin by fungi mycelia; (b) Lignin by enzyme suspension; (c) Mn^{+2} by enzyme suspension

SDS-PAGE Analysis

The SDS-PAGE analysis identified three protein bands in the crude enzyme sample, with molecular weights corresponding to LiP (38-40 kDa), MnP (53 kDa), and laccase (66 kDa).

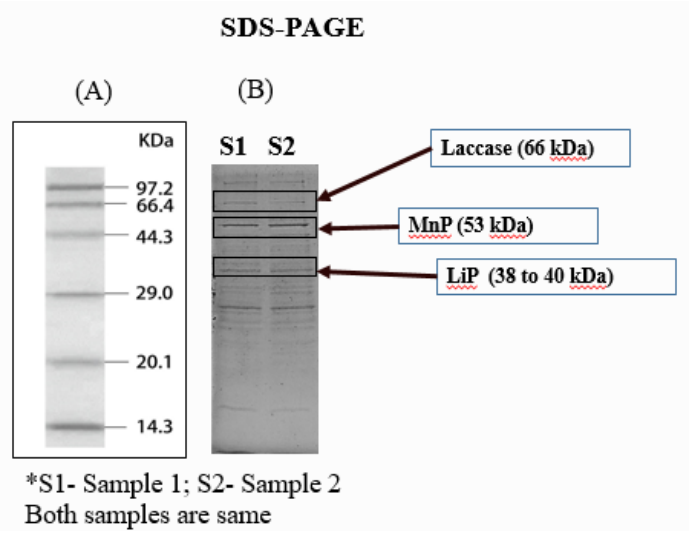


Figure 10: SDS-PAGE ; (A) ladder; (B) Samples band

Preparation of Nanoparticle-Based Enzyme Conjugates

Sodium alginate was used as a conjugating biopolymer to prepare nanoparticle-based enzyme conjugates. Different types of beads were formed by adding sodium alginate solution to $CaCl_2$ solution, with or without TiO_2 nanoparticles and enzyme extracts.

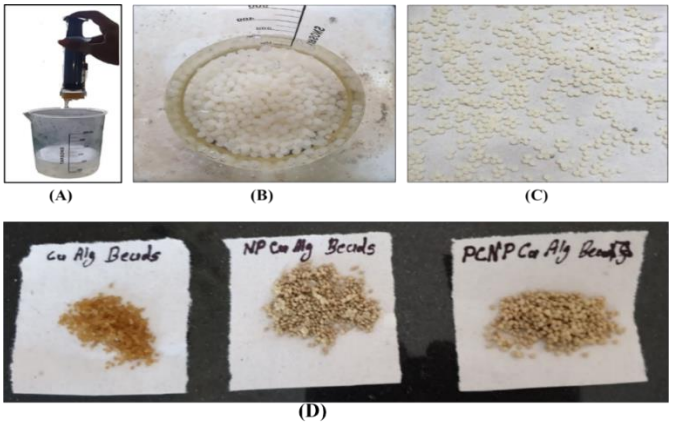


Figure 11: (A) Sodium alginate solution was added dropwise into a solution of 2% $CaCl_2$ solution, using 50mL syringe under constant stirring; (B) The formed beads in $CaCl_2$ solution; (C) Beads were transferred to filter paper for air-dry; (D) Different types of beads

Chapter 6: Treatment of leachates with Nanoparticle based enzyme conjugates and optimization of different parameters

Preparation of Nanoparticle-Based Enzyme Conjugates Using Chitosan (NpChBs)

Chitosan-based nanoparticle enzyme conjugates were prepared by dissolving 2.5 grams of chitosan in a 1% acetic acid solution, mixing in 1 gram of nitrogen-doped TiO_2 nanoparticles, and forming beads by dropping the solution into a 2% NaOH solution. The beads were cross-linked with glutaraldehyde and then incubated in a phosphate buffer with P. chrysosporium for 48 hours to ensure stable immobilization of the fungal culture.

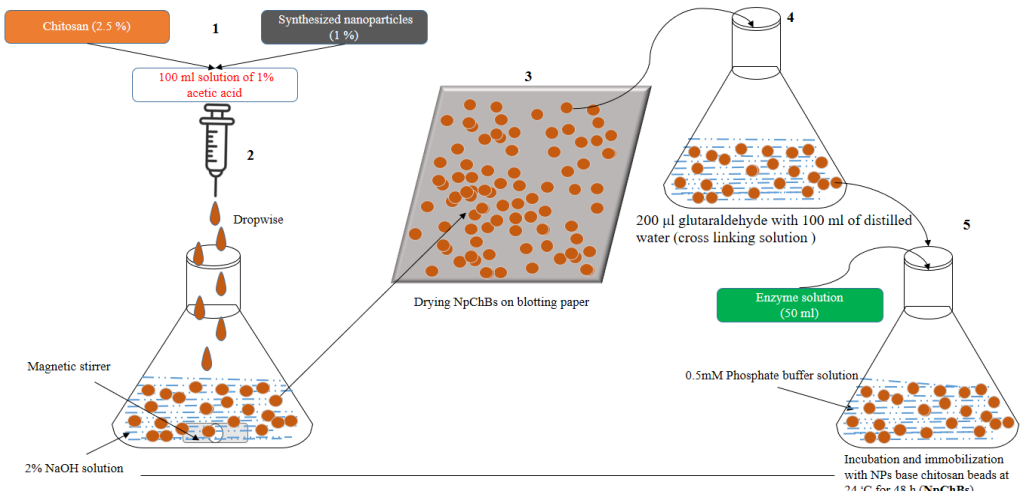


Figure 12: Diagram of preparation of nanoparticle-based enzyme conjugates (NpChBs)

SEM Analysis of NpChBs

SEM analysis provided insights into the structural properties and interactions of the chitosan beads with TiO_2 nanoparticles. The porous and rough surface morphology of the beads was observed, with darker spots indicating the successful incorporation of TiO_2 nanoparticles. The beads maintained structural integrity after exposure to enzyme solutions, despite some surface cracks.

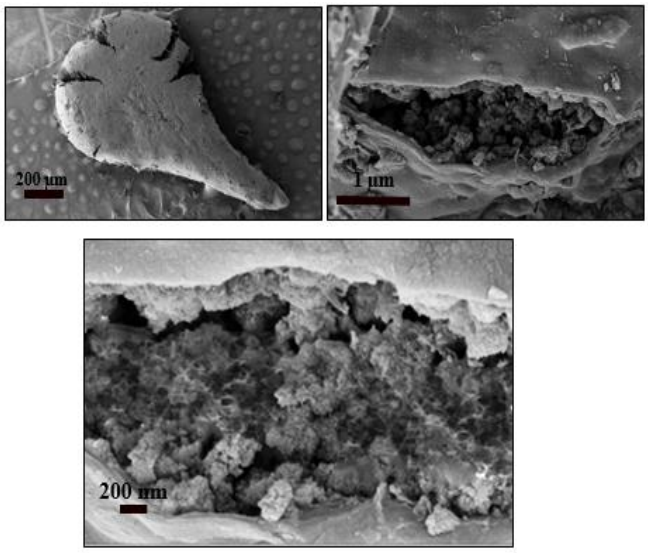


Figure 12: SEM image in native form at ×550 SEM image TiO_2 NPs embedded chitosan beads

Treatment of Leachate by NpChBs

A landfill leachate sample was treated using different configurations of nanoparticle-based enzyme conjugates in flasks. The configurations included raw leachate, leachate with nanoparticles embedded in chitosan beads, leachate with plain chitosan beads, and leachate with TiO_2 nanoparticles and enzyme-embedded chitosan beads. The treatment process was evaluated over 21 days under controlled conditions.

Results of Treatment of Landfill Leachate by NpChBs

Effect on pH

No significant changes in pH were observed across the various treatment samples, with pH levels remaining relatively constant around 9.6 to 9.7.

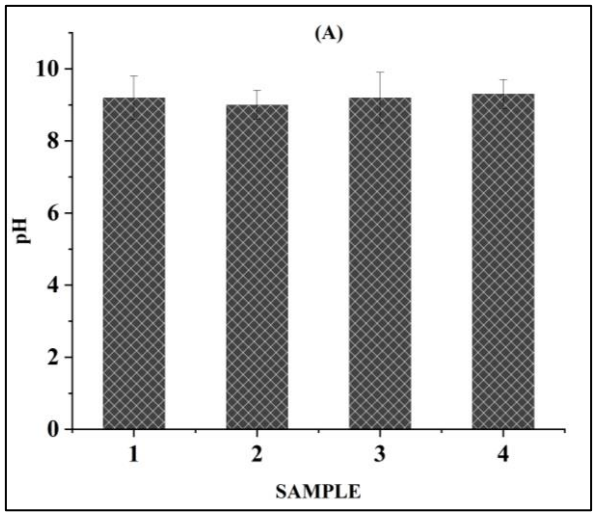


Figure 13: Treatment of leachate (21 days): Effect in pH

Effect on TDS & EC

TDS and EC values showed significant reductions, from 5100 ppm to 3400 ppm and from 10200 µS to 6800 µS, respectively, indicating effective removal of dissolved ions and pollutants.

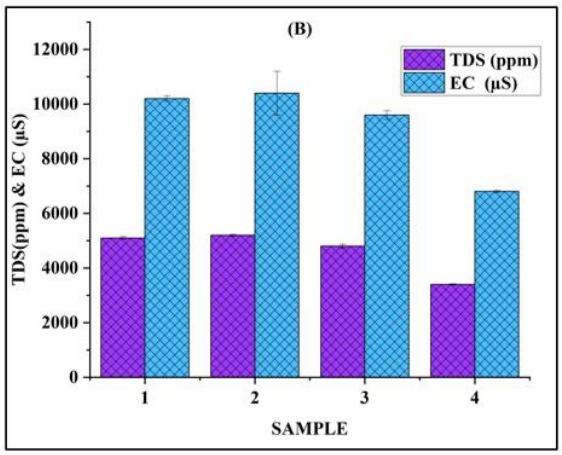


Figure 14: Treatment of leachate (21 days): Effect in TDS & EC

Effect on COD & NH_3–N

COD reduced from 6904±250 mg L^{-1} to 1680±126 mg L^{-1} (76%), and NH_3–N reduced from 1407±142 mg L^{-1} to 450±78 mg L^{-1} (68%) after 21 days of treatment.

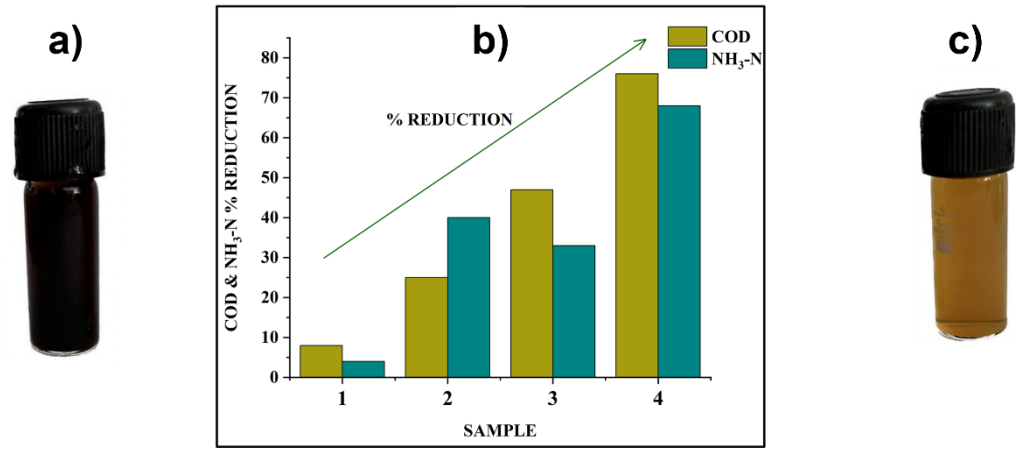


Figure 15: Treatment of leachate (21 days): (a) Raw leachate; (b); effect in COD & NH_3-N reduction (c) After treatment leachate

SEM and EDX Analysis

SEM and EDX spectra showed detailed structural and elemental composition of the TiO_2 nanoparticles and immobilized *P. chrysosporium* in chitosan beads, both before and after treatment, confirming successful incorporation and stability.

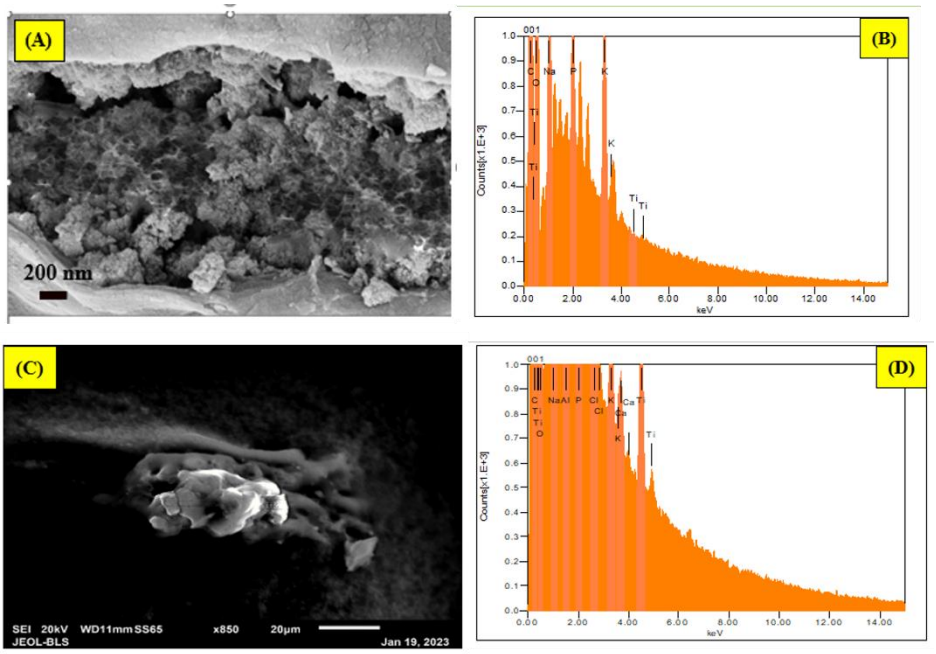


Figure 16: SEM images and EDX spectra of TiO_2 NPs & immobilized *P. chrysosporium*.suspension embedded chitosan beads. (A) in native form at ×550 SEM image, (B) in native form of the EDX, (C) after treatment at ×850 SEM image spectrum, (D) after treatment of the EDX

COD/BOD Ratio

The COD/BOD_3 ratio decreased from 8.4 to 3.9, indicating enhanced biodegradation efficiency and improved biodegradability of the leachate.

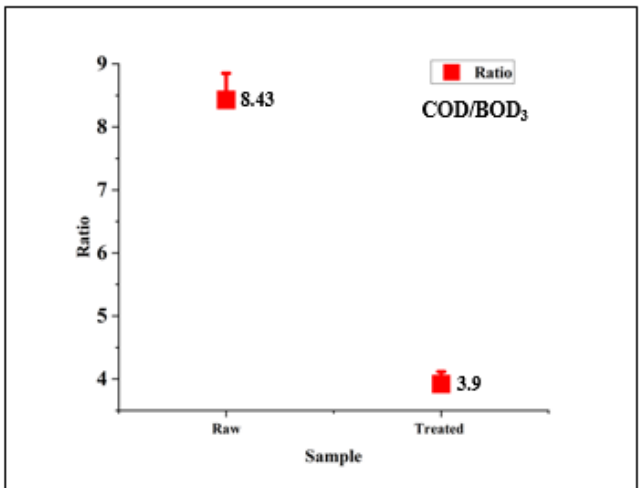


Figure 17: Values of the ratios COD/BOD_3 for raw leachate and treated leachate

The COD/BOD ratio uses for the different forms of waste water which are detailed below

1. COD/BOD < 2 = readily biodegradable effluent

2. COD/BOD < 4 = moderately biodegradable

3. COD/BOD > 4 = hardly biodegradable

GC-MS Analysis

GC-MS analysis before treatment revealed 48 distinct compounds, while post-treatment analysis detected only 25 compounds, demonstrating significant degradation and transformation of organic pollutants.

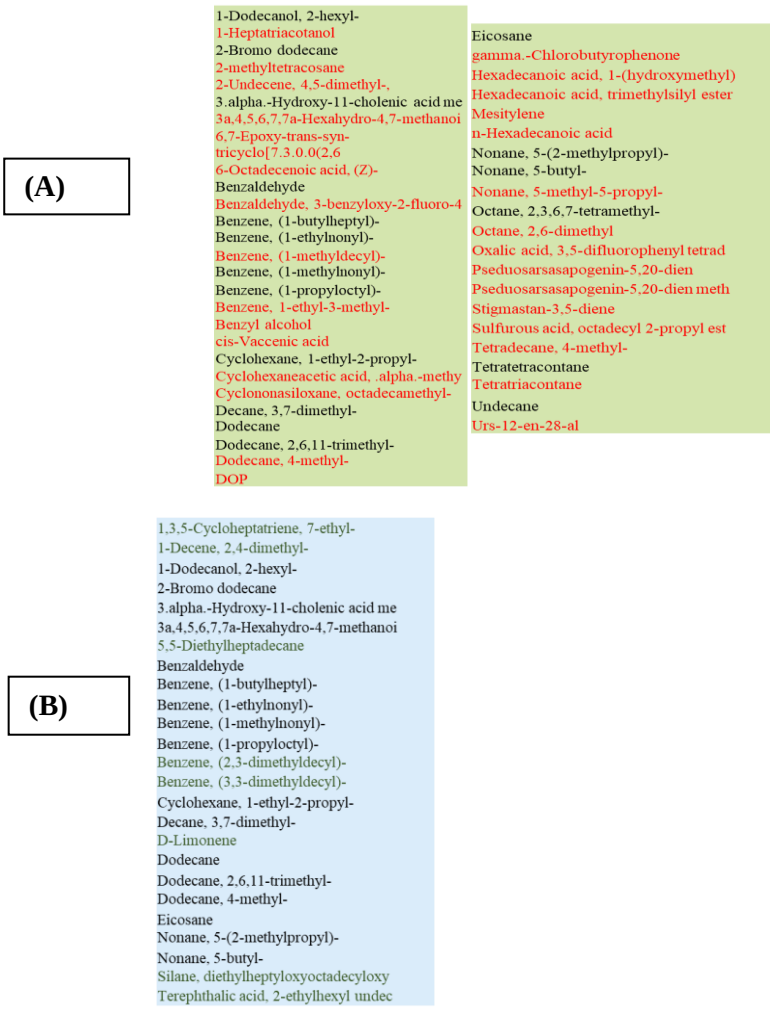


Figure 18: Compounds identified in (A) without treatment; (B) treated leachate

Chapter 5: Conclusion and Future Aspect

This research investigates the utility of nanoparticle-based enzyme conjugates in addressing the issue of landfill leachate. The research is of great importance due to the intricate nature and toxicity of leachate, which presents significant environmental and public health hazards. The primary objective of this study was to devise an innovative and effective solution for treating this hazardous waste.

The research initiative commenced with a comprehensive analysis of the leachate samples, uncovering a diverse array of contaminants, such as heavy metals, organic pollutants, and other hazardous substances. This essential information served as a foundation for evaluating the efficacy of the treatment methods. To this end, TiO_2 nanoparticles were synthesized and meticulously examined for their applicability in leachate treatment. The nanoparticles exhibited a remarkable surface area and demonstrated potent catalytic properties, making them ideal candidates for the breakdown of intricate pollutants.

The extraction of crude enzymes from the fungus *P. chrysosporium* was carried out, with an aim to characterize their ability to degrade organic pollutants. Subsequently, these enzymes were conjugated with synthesized nanoparticles to form nanoparticle-based enzyme conjugates (NpChBs). The efficacy of the NpChBs as a treatment for leachate was assessed under controlled conditions, resulting in noteworthy reductions in key pollutants, including COD, ammonia, and various organic compounds. The treatment process was optimized to enhance the catalytic and enzymatic activities, thereby establishing optimal conditions for pollutant degradation.

GC-MS analysis before and after treatment provided compelling evidence of the method's efficacy. The reduction in the number and complexity of detectable compounds after treatment indicated successful degradation of complex organic pollutants into simpler, less harmful substances. These findings highlight the potential of nanoparticle-based enzyme conjugates as a robust and effective solution for treating landfill leachate. The broad-spectrum efficacy of this method demonstrates its ability to address a wide range of pollutants, making it a promising tool for environmental protection and public health.

List of Publications

Research Paper

- **Vaidh, S.,** Surana, A., Nagariya, V., Rahewar, R., Prajapati, H., Patel, D., Pandya, A. and Vishwakarma, G.S., 2024. Amyloid fibril–bacterial cellulose nanohybrid membrane cartridge for efficient removal of heavy metal from industrial wastewater. *Water Quality Research Journal*, 59(2), pp.73-88.

- **Vaidh, S.,** Vaidya, P., Vaid, U. and Vishwakarma, G.S., 2021. Comparison of Adsorption Capability of Alginate Beads with Alginate Composite Beads for the Removal of Malachite Green Dye from Aqueous Solution (No. 6226). *EasyChair*.

- **Vaidh, S.,** Lakod, B., Kansara, U., Parekh, D. and Vishwakarma, G.S., 2022. Assessment of ground water quality of selected agricultural &industrial sites of Gandhinagar District Gujarat India.*Natural Sciences (The Journal of the Institute of Advanced Research), Vol. 3, Issue 1, 2022*.

- **Vaidh, S.,** Parekh, D., Vishwakarma, G.S., Investigate Leachate Treatment Potential of Fungus Crude Enzymes Immobilized with Metallic Nanoparticles, *Water Research and Technology* **(Under review) (IF-5.0)**

- Parekh, D., **Vaidh, S.,** Ailani, R., Banerjee, S. and Vishwakarma, G.S., 2024. Investigation of biochemical, enzymatic, and metagenomic profiles of garbage enzymes and its application in dumping site leachate treatment. *Environmental Science and Pollution Research*, pp.1-11. **(IF-5.8)**

- Parekh, D., **Vaidh, S.,** Patel, D. and Vishwakarma, G.S., 2022. Temporal study of physicochemical parameters of leachates and assessment of solid waste and ground water quality of Pirana dumping site, Ahmedabad, India. *Environmental Monitoring and Assessment*, *194*(10), pp.1-9. **(IF-3.3)**

Design Patent:

- **Gajendra Singh Vishwakarma, Sachin Vaidh**, Dharni Parekh and Alok Pandya; MULTI-SAMPLE ANALYZER AND SAMPLE TRAY FOR pH, TDS AND CONDUCTIVITY (Under filing stage. Application no : 202321026249)

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- **Vaidh, S.,** Parekh, D., Patel, D. and Vishwakarma, G.S., 2022. Leachate treatment potential of nanomaterial based assemblies: a systematic review on recent development. *Water Science and Technology*. (IF-2.43)

- Parekh, D., **Vaidh, S.,** Ailani, R., Banerjee, S. and Vishwakarma, G.S., 2022 Kitchen Waste Derived Enzymes and Organic Acids in Leachate and Industrial Wastewater Treatment: A Review. *Microchemical Journal*. (Under Review) (IF-5.3)

- Thakkar,S., Rana, Y., **Vaidh, S.,** Banerjee, J., Banerjee, S .,Viswakarma, G.S., Anthropogenic effects of Endocrine Disrupting Hazardous Chemicals (EDCs) on human reproductive health and related malignancies. *Journal of Water and Health.* (Under Review) (IF-2.3)

Book Chapter

- Verma, N., **Vaidh, S.,** Vishwakarma, G.S. and Pandya, A., 2020. Antimicrobial nanomaterials for water disinfection. In *Nanotoxicity* (pp. 365-383). Elsevier. (Published)

- Bhattacharjee, G., Gohil, N., **Vaidh, S.,** Joshi, K., Vishwakarma, G.S. and Singh, V., 2020. Microbial bioremediation of industrial effluents and pesticides. In *Bioremediation of pollutants* (pp. 287-302). Elsevier. (Published)

- Kumar, R., **Vaidh, S.,** Parekh, D., Vasoya, N., Shah, M. and Vishwakarma, G.S., 2022. Self-assembled nanomaterials for cleansing and bioremediation. In *Design, Principle and Application of Self-Assembled Nanobiomaterials in Biology and Medicine* (pp. 251-258). Academic Press. (Published)

Participation Program (Paper/Poster/Workshop)

Paper Presentation

- International Conference on Current Research in Applied and Fundamental Sciences-2021 (CRAFTS-2021) Organized by School of Science, Sandip University, Nashik
- National Conference on Advanced Research Techniques in Chemical Engineering (ARTCHEM-2022) Department of Chemical Engineering Sarvajanik University Sarvajanik College of Engg & Technology, Surat, Gujarat.
- Two-day International Conference on Soil, Water, and Air Pollution organized by the School of Environmental Studies, Cochin University of Science and Technology, Kochi-682022, India, during 27 -28, October 2022. (Co-author)

Poster Presentation

- National Seminar on Current Trends in Environment Sciences: Issues and Challenges (2022) Organized by National Forensic Sciences University, Gandhinagar
- National Conference on Synthetic Biology for Reprograming Organized by Department of Biosciences, Indrashil University
- National Conference on "Advances In Genetic Engineering And Plant-Microbes Interactions" Organized by IAR, Gandhinagar
- Annual Research & Innovation Conclave 2023(ARIC-2023) organized by Institute of Advanced Research, Gandhinagar, INDIA (2^{nd} Prize)

Workshop

- STUTI Workshop on Spectroscopic, Chromatographic, Bioanalytical & Imaging Techniques Organized by: Central University of Punjab, Bathinda, Punjab
- Two days' workshop on "Training on Basics of Cartography: T-121" organized by Cartography Lab, Department of Earth Sciences, Gujarat University, Ahmedabad

- SERB sponsored Hands on workshop on Tools and Technique of Water Quality Monitoring, Sampling, Analysis and Quality assurance organized by Amity Institute of Environmental Sciences.
- National level workshop on " *Animal cell culture techniques and apoptosis detection assays"* organized by Institute of Advance Research, Gandhinagar and Gujarat State Biotechnology Mission
- Hands-On Workshop On Biosensor Technology, Organized by IAR, Gandhinagar